SECTION 2
WATER QUALITY MONITORING PROGRAMS

In 1998, the King County Department of Natural Resources (DNR) operated two wastewater treatment plants and two CSO treatment plants with outfalls discharging directly into Puget Sound marine waters. The Clean Water Act states that all wastewater collection and treatment facilities that discharge effluent into surface waters are required to have a National Pollutant Discharge Elimination System (NPDES) permit. In Washington, the Washington State Department of Ecology (DOE) administers this program by delegation from the U.S. Environmental Protection Agency (EPA).

The NPDES permit sets limits on the quality and quantity of treated wastewater that is discharged through individual outfalls. In compliance with NPDES requirements and to verify that the facilities are meeting the goals of the Clean Water Act, King County has conducted an extensive point source monitoring program for over 20 years to assess the quality of each facility's effluent, the receiving water around each outfall, and nearby beaches.

Water quality may be affected by two types of pollution: point source and nonpoint source. Point source pollution is defined by its entry into the aquatic environment from a specific location, such as an outfall pipe, and can be generated from a variety of industrial and municipal facilities, such as sewage treatment plants and manufacturing facilities. Nonpoint source pollution comes from any source that is not a point source and includes runoff from streams, groundwater, storm water, etc. Land use, such as agricultural and urban usage, affects the quality of the runoff. King County's marine monitoring program is designed to assess potential effects from both types of pollution in both nearshore and offshore environments. The stations monitored by the program fall into one of two categories; ambient (or nonpoint source) and point source. Within these categories, stations are classified as either intertidal (littoral zone to mean lower low water) or offshore (bottom depth greather than 10 feet).

Observing conditions in areas that do not demonstrate direct effects from individual point sources provide essential background water quality data. King County has established a marine ambient monitoring program in the Central Puget Sound Basin, with stations well removed from the influence of point source discharges. King County's goals for ambient monitoring are to better understand the regional water quality problems, establish priorities for preventative actions, and provide background data needed to identify trends that might indicate impacts from long-term cumulative pollution. An overview of the County's marine monitoring program is provided below in Figure 2-1 and can also be found in Table 2-1.

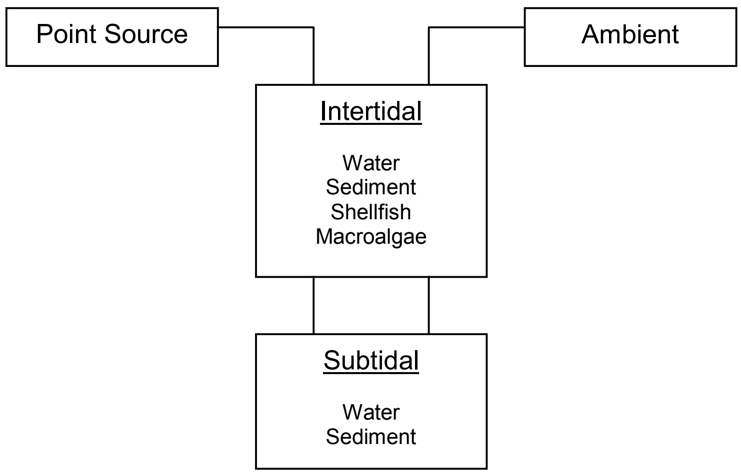

Figure 2-1. Overview of Matrices Sampled

AMBIENT AND POINT SOURCE MONITORING PROGRAMS

The ambient and point source monitoring programs focus on marine waters and their underlying sediments. Many marine pollutants are in particulate form. As these contaminated particles settle out of the water column, pollutant concentrations in the underlying sediments tend to increase. Most sources of contamination are found in nearshore areas where pollutants tend to accumulate in sediments close to these sources. Benthic organisms that live on or in contaminated sediments tend to accumulate these contaminants through contact or ingestion (bioaccumulation). Pollutants also tend to concentrate as they move from one trophic level to the next (biomagnification), as contaminated organisms become prey to animals higher up in the food web. Contaminated sediments have an important impact on human and marine environmental health, especially in nearshore areas which are generally high contact areas for marine organisms and people.

Table 2-1. Summary of 1998 Monitoring Program

Location	Matrix	Parameter	# of Stations Sampled *Ambient*	*Point Souce*
Intertidal	Water	Bacteria	16	6
	Sediment	Organics	3	3
		Metals	3	3
		Conventionals [1]	3	3
	Shellfish	Organics	2	2
		Metals	2	2
		Bacteria	6	3
	Macroalgae	Metals	4	3
Subtidal	Water	Bacteria	5	5
		GWQP [2]	5	5
	Sediment	Organics	10	19
		Metals	10	19
		Conventionals	10	19
		Benthic infauna	--	6
		Toxicity tests	--	2

[1] Conventionals include total solids, total volatile solids, total sulfide, total organic carbon, and grain size.
[2] GWQP = general water quality parameters.

Nutrients and pathogens which may cause water quality problems in marine waters are also typically seen in nearshore area in the vicinity of contamination sources. While excess nutrients do not cause immediate harm to organisms living in the water column, excess nutrients can increase the amount of phytoplankton and algae which can deplete oxygen to levels incapable of sustaining aquatic organisms when it decays.

Marine Ambient Monitoring Program

The 1998 ambient monitoring program included sampling and analysis of intertidal and offshore water, sediment, shellfish tissue, and macroalgae collected from 32 stations (see Table 2-1). This program provides background information for comparison of data obtained from the point source monitoring program. Parameters measured included physical properties such as water clarity and temperature, and nutrient abundance (nitrogen and phosphorus compounds as well as silica). Dissolved oxygen, chlorophyll, and bacteria were also monitored. Organic compounds (e.g., polynulcear aromatic hydrocarbons, pesticides, and polychlorinated biphenyls), metals, and bacteria were monitored in intertidal and subtidal sediments. Figure 2-2 shows ambient monitoring station locations and Table 2-2 gives a summary of parameters measured at each station. Station coordinates are given in Appendix E.

Marine Point Source Monitoring Program

King County collected subtidal water, sediment, shellfish tissues, and macroalgae samples for the 1998 point source monitoring program at 29 stations. Point source stations include those that are required by the County's NPDES permit (eg., subtidal sediment sites near the West Point Treatment Plant outfall) and those that are not required but are in close proximity to point source discharges (eg., intertidal stations near the West Point Treatment Plant). Station locations are presented in Figure 2-3 and station coordinates are provided in Appendix E.

Water was analyzed for temperature, salinity, water clarity, dissolved oxygen, nutrients, chlorophyll and bacteria. Sediment was analyzed for organic compounds, metals, conventional parameters (such as total organic carbon, total sulfides, and grain size). Benthic infauna and toxicity tests were also conducted for several stations (Table 2-3).

Both fecal coliform and enterococcus bacteria were measured in water, sediment, and shellfish tissues. Enterococcus is being considered as an indicator of bacterial contamination in marine waters, therefore, both types of bacteria were analyzed in anticipation of possible changes in bacterial monitoring procedures. Although there are no regulatory standards for fecal coliform bacteria in shellfish tissues, samples were analyzed for informative purposes.

Figure 2-2. 1998 Ambient Monitoring Stations

Table 2-2. 1998 Ambient Monitoring Stations and Parameters Measured

			SEDIMENT			WATER		SHELLFISH			ALGAE
STATION	LOCATION	OFFSHORE/ INTERTIDAL	Organics*	Metals	Conventionals	Bacteria	GWQP **	Organics	Metals	Bacteria	Metals
KSBP01	Point Jefferson	Offshore				◆	◆				
KSRU02	LW Ship Canal	Offshore				◆	◆				
LSNT01	Dolphin Point	Offshore				◆	◆				
JSTU01	Point Wells	Offshore				◆	◆				
KSPS01	Shilshole Bay	Offshore	◆	◆	◆						
LSML01	West Seattle	Offshore	◆	◆	◆						
LTDF01	inner Elliott Bay	Offshore	◆	◆	◆						
LSCI01	central basin	Offshore	◆	◆	◆						
LSCK01	central basin	Offshore	◆	◆	◆						
LSCW02	outer Elliott Bay	Offshore	◆	◆	◆						
LSDZ01	inner Elliott Bay	Offshore	◆	◆	◆						
LSEZ01	inner Elliott Bay	Offshore	◆	◆	◆						
LTCA02	inner Elliott Bay	Offshore	◆	◆	◆						
LTED04	Elliott Bay	Offshore	◆	◆	◆	◆	◆				
JSWX01	Richmond Beach	Intertidal				◆					
JSVW04	Richmond Beach	Intertidal	◆	◆	◆	◆		◆	◆	◆	◆
KSXS02	Magnolia	Intertidal	◆	◆	◆						◆
KSUR01	Magnolia bluff	Intertidal									◆
MTEC01	Seahurst Park	Intertidal	◆	◆	◆	◆				◆	
KSLU03	Golden Gardens	Intertidal				◆				◆	
MTLD03	Normandy Park	Intertidal				◆		◆	◆	◆	
MSSM05	Tramp Harbor	Intertidal				◆				◆	
KRJY01	Fay Bainbridge	Intertidal				◆				◆	
KSQU01	Shilshole Bay	Intertidal				◆					
KSYV02	Magnolia	Intertidal				◆					◆
LTAB01	inner Elliott Bay	Intertidal				◆					
LTEH02	inner Elliott Bay	Intertidal				◆					
LSGY01	Seacrest	Intertidal				◆					
LSFX01	Duwamish Head	Intertidal				◆					
LSHV01	West Seattle	Intertidal				◆					
LSTU01	Lincoln Park	Intertidal				◆					
LSVW01	Fauntleroy Cove	Intertidal				◆					

* Includes semi-volatile organics, pesticides, and PCBs.
** GWQP = general water quality parameters

Figure 2-3. 1998 Point Source Monitoring Stations

Table 2-3. 1998 Point Source Monitoring Stations and Parameters Measured

			SEDIMENT				WATER		SHELLFISH			ALGAE
STATION	LOCATION	OFFSHORE/ INTERTIDAL	Organics *	Metals	Conventional	benthic comm	Bacteria	GWQP **	Organics	Metals	Bacteria	Metals
WP430N	West Point outfall	Offshore	◆	◆	◆							
WP215N	West Point outfall	Offshore	◆	◆	◆							
WP230P	West Point outfall	Offshore	◆	◆	◆							
WP215S	West Point outfall	Offshore	◆	◆	◆							
WP430S	West Point outfall	Offshore	◆	◆	◆							
WPD430N	West Point outfall	Offshore	◆	◆	◆	◆						
WPD215N	West Point outfall	Offshore	◆	◆	◆	◆						
WP230D	West Point outfall	Offshore	◆	◆	◆	◆						
WPD215S	West Point outfall	Offshore	◆	◆	◆	◆						
WPD430N	West Point outfall	Offshore	◆	◆	◆	◆						
WP1500N	West Point outfall	Offshore	◆	◆	◆							
WP1500S	West Point outfall	Offshore	◆	◆	◆	◆						
KSSK02	West Point outfall	Offshore					◆	◆				
KSSN04	West Point	Intertidal	◆	◆	◆		◆		◆	◆	◆	◆
KSSN05	West Point	Intertidal					◆					◆
LSEP01	Renton outfall	Offshore					◆	◆				
CP245/W310	Carkeek Park	Offshore	◆	◆	◆							
CP246/W312	Carkeek Park	Offshore	◆	◆	◆							
CP246/W315	Carkeek Park	Offshore	◆	◆	◆							
CP246/W319	Carkeek Park	Offshore	◆	◆	◆							
CP248/W308	Carkeek Park	Offshore	◆	◆	◆							
KSIV01	Carkeek Park	Offshore	◆	◆	◆							
KSIW02	Carkeek Park	Offshore					◆	◆				
KSHZ03	Carkeek Park	Intertidal	◆	◆	◆		◆				◆	
KTHA01	Carkeek Park	Intertidal					◆					
LSKR01	Alki Point	Intertidal	◆	◆	◆		◆		◆	◆	◆	◆
LSKS01	Alki Point	Intertidal					◆					
LSKQ06	Alki outfall	Offshore					◆	◆				
LTBC41	Denny Way	Offshore	◆	◆	◆		◆	◆				

* Includes semi-volatile organics, pesticides, and PCBs. Organotins were analyzed for subtidal sediments.
** GWQP- general water quality parameters.

WATER COLUMN MONITORING

Water column monitoring is an important component of the County's water quality monitoring programs and is structured to detect natural seasonal changes in the water column as well as identify changes from anthropogenic input. General water quality parameters (temperature, salinity, transparency, dissolved oxygen, chlorophyll-*a*, phaeopigment, ammonia, nitrate+nitrite, total phosphorus, silica, and total suspended solids) are monitored at multiple depths for ten sites. Temperature, salinity, and bacteria are the only parameters measured at station KSRU02 located near the mouth of the Lake Washington Ship Canal. Bacteria are monitored at all 32 sites.

Bacteria

Biologists and agencies responsible for protecting public health define water quality in terms of several variables, one of those being the presence of bacteria. Fecal coliform bacteria are found in the feces of humans and other warm-blooded animals. These bacteria may enter the aquatic environment directly from humans and animals, from agricultural and storm runoff, and from wastewater. Although fecal coliform bacteria are usually not pathogenic, they may occur along with disease-causing bacteria so their presence indicates the potential for pathogenic bacteria to be present. Generally, a high fecal coliform count suggests that there is a greater possibility for pathogenic bacteria to be present. Fecal coliform bacteria are typically found in higher numbers than pathogenic bacteria and are easier and safer to test in the laboratory.

Regulatory standards have been established for acceptable levels of fecal coliform bacteria for various water uses, including recreation and fish and wildlife habitat. It should be noted that although fecal coliform bacteria are commonly used as an indicator for the presence of pathogens, there are limitations to the use of these data. There is no recognized numerical association between the number of fecal coliform bacteria and the number of pathogens measured in a sample. In addition, the presence of viruses and naturally occurring toxic organisms (such as dinoflagellates) are not indicated by the presence of fecal coliforms, therefore, these organisms must be measured independently.

Temperature and Salinity

Water temperature is an important factor in an estuary. As water temperature rises, biological and chemical activity increases while the capacity of water to hold dissolved oxygen decreases. Water temperature is dependent upon various factors, including depth, season, amount of mixing from tides, wind, storms, amount of freshwater input, and degree of stratification.

Both temperature and salinity influence water column stratification, although salinity is more important in determining stratification in estuaries. Estuaries usually exhibit changes in salinity as freshwater input increases or decreases. Salinity also fluctuates with tides, amount of input of high salinity water from deep Pacific oceanic water, amount of precipitation, and degree of water column mixing from winds. Generally, salinity increases with water depth unless the estuary is well-mixed.

Dissolved Oxygen

Dissolved oxygen concentration is an important factor controlling the presence or absence of marine species. Aquatic plants and animals require a certain amount of oxygen dissolved in the water for respiration and basic metabolic processes. Waters that contain high amounts of dissolved oxygen are generally considered healthy ecosystems and are capable of sustaining various species of aquatic organisms.

Several factors influence dissolved oxygen concentrations. Seasonal climatic fluxuations can cause water temperature to rise in the spring and summer, reducing the capacity of water to hold dissolved oxygen. In winter, deep oceanic water from the Pacific Ocean containing naturally low levels of oxygen enters Puget Sound. Moreover, anthropogenic input of organic matter and phytoplankton decay may decrease levels of oxygen. Bacteria that utilize organic matter for food consume dissolved oxygen. Hypoxia results when the rate of oxygen consumption mostly by bacteria decomposing organic material in the water column exceeds the rate of oxygen production by photosynthesis and by replenishment at the air/water interface from the atmosphere. When the system is overloaded with organic material, oxygen consumption by bacteria may increase to the point where conditions can no longer support marine life (eutrophication), putting fish and other aquatic organisms at risk.

Transparency

Transparency (or water clarity) is measured to determine the depth to which enough light penetrates to support plant growth (euphotic zone). Several factors affect transparency including the amount of suspended silt and soil particles and the amount of phytoplankton and zooplankton in the water column. In addition to transparency, total suspended solids are also monitored. Freshwater input (particularly after storms) and wave action also affect transparency. Low transparency conditions which persist over an extended period of time can degrade the health of a water body as the decreased amount of light penetration reduces the area for aquatic plants and primary producers to grow. In addition, many marine organisms feed by filtering water and large amounts of suspended matter may obstruct their filter-feeding systems.

Nutrients

The addition of nutrients, such as nitrate and phosphate, into marine waters can have a considerable effect on the water quality, particularly for nearshore habitats where nutrient input typically occurs and tends to be confined. Nutrients may enter marine waters from wastewater discharges, nonpoint runoff, and from riverine and oceanic sources. The greatest impact these nutrients may have is the sudden increase in aquatic plant growth, or biomass.

The amount of light that penetrates the water column and the amount of nutrients in the water column affect phytoplankton growth. Nitrogen is the primary limiting nutrient that determines the growth of phytoplankton in marine waters (Valiela, 1984). Although nitrogen occurs naturally in the marine environment, abnormal increases from sources such as wastewater or fertilizers can cause significant increases in phytoplankton growth. An increase in phytoplankton biomass may cause a decline in dissolved oxygen as the phytoplankton cells respire and decay. This depression in dissolved oxygen levels can become critical in areas of reduced circulation. The marine waters within King County have not experienced any significant eutrophication problems, mainly due to the high degree of mixing in the central basin of Puget Sound (PSWQAT, 2000).

Nitrogen Compounds. Nitrate, nitrite, and ammonium are forms of inorganic nitrogen used by phytoplankton in the aquatic environment. Nitrates and nitrites are formed through the oxidation of ammonium by nitrifying bacteria. As mentioned above, nitrogen is usually the limiting nutrient in marine waters. Therefore, an increase in nitrogen compounds could lead to phytoplankton blooms. When blooms occur, water conditions (such as reduced water clarity and dissolved oxygen) may become unfavorable for aquatic organisms. Input of nitrogen compounds may originate from sources such as wastewater from municipal discharges and agricultural runoff.

Phosphorus. Phosphorus is an essential element for aquatic plants and a fundamental element in the metabolic process for both plants and animals. Total phosphorus includes both organic phosphorus and inorganic phosphate. Inorganic phosphates are rapidly taken up by algae and other aquatic plants, although phosphates are usually not the limiting nutrient in marine waters. However, large inputs could cause algal blooms which could lead to unfavorable conditions. Sources of phosphorus potentially entering the marine environment include wastewater from municipal discharges, industrial wastes, nonpoint agricultural runoff, rivers and streams, and the Pacific Ocean.

Silica. Silica is a micronutrient needed by diatoms, radiolarians, some sponges and other siliceous organisms for skeletal growth. Silica can be used as an indicator of plankton blooms, along with chlorophyll-*a*, as silica concentrations will decrease in the photic zone from an increase in phytoplankton uptake. Sediments act as a sink for silica which may be regenerated by various physical and biological processes and reused by organisms on the seafloor and in overlying waters.

Chlorophyll and Pheopigments

Chlorophyll-*a* is a green pigment used by algae and green plants during the process of photosynthesis to convert light, carbon dioxide, and water to sugar. Chlorophyll-*a* concentration is the most direct indicator of phytoplankton biomass since all marine planktonic algae contain this photosynthetic pigment. However, chlorophyll-*a* concentrations are not an exact assessment of phytoplankton abundance. The ratio of phytoplankton biomass to chlorophyll varies with species, nutritional status, and environmental conditions. Pheopigments, such as pheophorbide-*a* and pheophytin-*a*, are degradation products of chlorophyll and are produced when phytoplankton cells are grazed upon by zooplankton. High concentrations of pheopigments relative to chlorophyll a indicate a high level of grazing in an aquatic ecosystem. Several factors influence phytoplankton abundance, including amount of solar radiation, extent of grazing, water temperature, nutrient availability, and water column stratification.

Water Column Sampling Methods

Field Methods. Subtidal water column samples were collected in accordance with the *Recommended Guidelines for Sampling Marine Sediment, Water Column, and Tissues in Puget Sound* (PSEP, 1996) by the King County Environmental Services Section. A brief description is provided below.

Subtidal water samples were collected from the *R/V Liberty*, a 42-ft boat, equipped with a hydraulic crane on the rear-deck. From January to the end of October, samples were collected by mounting 5-liter Niskin bottles at specified depths on a weighted hydro-wire and lowering the bottles using a hydraulic boom. Once the bottles were in place, the boom operator inititated the tripping sequence by releasing a messenger on the wire. Bottles were retrieved and samples immediately placed into sample containers. Starting at the end of October, subtidal water column profiles were sampled by a SeaBird Electronics Model 25 conductivity-temperature-depth (CTD) profiler. Parameters measured by the CTD included: temperaure, salinity, density, dissolved oxygen, photosynthetically active radiation (PAR), optical backscatterance, and chlorophyll-*a*. The CTD was lowered into the water using a hydraulic boom and allowed to equilibrate for 5 minutes at the surface before being lowered to a few meters from bottom depth. Five-liter Niskin bottles were mounted onto the CTD for collecting discrete water samples at predetermined depths for nutrients, total suspended solids, and bacteria samples. The CTD was electronically programmed to trip individual bottles at specific depths. All bottles were programmed to trip as the CTD ascended through the water column. The CTD was then brought on deck and discrete water samples were immediately drawn from the Niskin bottles and placed into appropriate sample containers. Dissolved oxygen samples were immediately preserved with a minimum of 2 milliliters (mL) of $MnSO_4$ (manganous sulfate) and 2 mL of AIA (alkali iodide azide), then stored in the dark. With the exception of dissolved oxygen bottles, sample containers were stored on ice until delivered to the King County Environmental Laboratory.

Transparency (water clarity) measurements were collected using an 8-inch-diameter black-on-white Secchi disk. Secchi depths were recorded to the nearest 0.5 meter. As readings may vary depending upon environmental conditions (e.g., waves and glare) and the individual collecting the reading, all field crew were trained to collect measurements using the same procedure. From January to the end of October, temperature measurements were obtained with a digital thermometer and recorded to the nearest tenth of a degree Celsius (^{o}C). From the end of October to the end of December, temperature measurements were collected using the CTD.

Intertidal water samples were collected by inverting sampling bottles just below the water surface and then capping the bottle before removing the container. Samples were collected from approximately knee-deep water when possible. At some sites where accessibility is difficult, such as LTAB01 located in Elliott Bay, samples were collected with a container lowered on a rope and then transferred into the sample container.

Laboratory Methods. With the exception of temperature, Secchi disk transparency, and CTD parameters which were measured in the field, all water column parameters were analyzed at the King County Environmental Laboratory. Laboratory methods and detection limits are provided in Table 2-4.

Fecal coliform and enterococcus bacteria were analyzed according to Standard Methods 9222D and 9230C, respectively (APHA, 1992).

All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and spikes where appropriate. All data were reviewed by section supervisors prior to entry into the LIMS (Laboratory Information Management System) database.

SEDIMENT MONITORING

Sediment monitoring is a component of the County's ambient and point source monitoring programs as many pollutants (organics and trace metals) tend to be associated with particles that settle out onto bottom sediments. At sufficient concentrations, these compounds may be harmful to benthic organisms and may be bioaccumulated. Conventional parameters (total solids, total volatile solids,

Table 2-4. Laboratory Methods and Detection Limits for General Water Quality Parameters

Parameter	Units[1]	MDL[2]	RDL[3]	Method [4]
Salinity	psu	0.005	0.01	SM2520-B
Dissolved Oxygen	mg/L	0.5	1	SM4500-O-B
Chlorophyll-*a*	mg/m^3	0.01	0.05	SM10200-H
Phaeophytin	mg/m^3	0.01	0.05	SM10200-H
Ammonium (NH_4^+)	mg/L	0.02	0.04	SM4500-NH3-H
Nitrite+Nitrate (NO_3+NO_2)	mg/L	0.05	0.1	SM4500-NO3-F
Total Phosphorous	mg/L	0.005	0.01	SM4500-P-B,E
Total Suspended Solids (TSS)	mg/L	0.5	1	SM2540-D
Silica (SO_4)	mg/L	0.05	0.1	SM4500-SI-D

[1]psu = practical salinity units
mg/L = milligram per liter
mg/m^3 = milligram per meter cubed
[2] MDL = method detection limit
[3] RDL = reported detection limit
[4] Source = APHA 1992

grain size distribution, total organic carbon, and total sulfides) are also monitored as these parameters affect the bioavailability and/or toxicity of pollutants as well as influence the concentration of pollutants accumulated. A more detailed description of why conventional parameters are measured is provided below.

Total Solids

Total solids are the inorganic and organic particles remaining after a sediment sample has been dried. This parameter is measured in order to convert chemical concentrations from a wet weight to a dry weight basis for uniformity.

Total Volatile Solids

Volatile solids are primarily organic solids that burn in the presence of oxygen at a given temperature (usually 550 or 600 ^oC). The solids or ash remaining behind is comprised of the non-volatile or fixed solids. The volatile solid value is used as an estimate of organic matter in a sample.

Grain Size Distribution

This is a measure of the size range of particles contained in a given sample. Grain size is usually separated into four main categories: silt, clay, sand, and gravel. Grain size has an influence on chemical concentrations found in sediments and sediments with a large proportion of small particles (silt and clay) tend to have higher chemical concentrations.

Total Organic Carbon

This is a measure of the total amount of particulate and nonparticulate organic carbon contained in a sample. In the same manner as grain size, total organic carbon also has an influence on chemical concentrations contained in sediments. The higher the organic carbon content, the higher chemical concentrations tend to be. This is particularly true for organic compounds.

Total Sulfides

Sulfides are formed by the anaerobic breakdown of organic matter. Total sulfides represent the amount of all sulfide compounds in a given sample, and are measured as they may be toxic to some benthic organisms at low concentrations and can create unaesthetic conditions for humans.

Sediment Sampling Methods

Field Methods. Subtidal sediment samples were collected by the King County Environmental Services Section from the *R/V Liberty*, a 42-foot boat equipped with a hydraulic crane on the rear-deck. Samples were collected with two stainless steel 0.1-m^2 modified van Veen grab samplers deployed in tandem. The sampler was decontaminated between sites by scrubbing with a brush to remove excess sediment, followed by an on-board rinsing and thorough *in-situ* rinsing. If sample acceptability criteria were met, the top two centimeters of sediment from a minimum of five subsamples were composited and homogenized before transference to the appropriate sample containers. Sediment samples were collected in accordance with the *Puget Sound Estuary*

Program (PSEP) Recommended Protocols (PSEP, 1996) and the County's *Standard Protocol for Marine Sediments* (King County, 1997).

Intertidal samples were collected by hand-held core tubes. Once the required sample amount was obtained, sediments were homogenized in a stainless steel bowl before being transferred to appropriate sample containers. All sampling equipment was site-specific and not reused. All samples were stored on ice until submitted to the laboratory.

Amphipods used for toxicity testing were collected off West Beach on Whidbey Island at a water depth of 60 meters or less. Contents of the van Veen sampler were sieved through a 1-mm stainless screen. The retained amphipods were then washed into a clean cooler containing unsieved sediment and seawater from the collection site. Upon arrival at the laboratory, the cooler was placed in a 15^{o}C environmental chamber.

Laboratory Methods. The King County Environmental Laboratory analyzed all chemical parameters with the exception of particle size distribution and total sulfide. These two analyses were performed by a subcontracted laboratory. Methods and detection limits are provided in Table 2-5. All metals were analyzed using inductively coupled plasma (ICP) emission spectrometry with the exception of mercury. Mercury was analyzed by cold-vapor atomic absorption spectrophotometry. Semivolatile organics were extracted with an organic solvent and then analyzed by gas chromatography/mass spectrometry (GC/MS). Pesticides and PCBs were extracted with organic solvents and then analyzed using a gas chromatograph equipped with an electron capture detector (ECD). All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes where appropriate. All data were reviewed by section supervisors prior to entry into the LIMS database.

Sediment toxicity tests are performed on sediments collected from around the wastewater treatment plant outfalls which exceed state standards for chemical parameters. Three sediment toxicity tests were performed in 1998. A 10-day acute toxicity test using the amphipod *Rhepoxynius abronius* was conducted by the KCEL according to *Recommended Guidelines for Conducting Bioassays on Puget Sound Sediments* (PSEP, 1995). Mortality is the primary endpoint for this test. Sublethal endpoints, such as emergence of amphipods during the

Table 2-5. Laboratory Methods and Detection Limits for Sediment Parameters

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Volatile Solids	%	0.005	SM2540-G
Total Oil & Grease	mg/kg	100	SM5520-B
Total Organic Carbon	mg/kg	5	SM5310-G
Total Sulfide	mg/kg	10	SM4500-S
Metals, total, ICP	mg/kg	variable[1]	Metro 16-02-004
Mercury, total, CVAA	mg/kg	0.019	Metro 16-01-001
Semivolatile Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8080
Organotins	µg/kg	0.3	NAOO, 1989
Grain Size Distribution	%	---	PSEP, 1991

[1]Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendix B.

exposure period and failure to rebury in sediment at the end of the test were also recorded.

A 96-hour acute toxicity echinoderm embryo test using the sea urchin *Strongylocentrotus purpuratus* was also conducted by the KCEL according to *Standard Guide for Conducting Statis Acute Toxicity Tests with Echinoid Embryos* and *Recommended Guidelines for Conducting Bioassays on Puget Sound Sediments* (PSEP, 1995). Sea urchins were obtained from a commercial supplier. A combined measure of mortality and abnormal development (effective mortality) is the primary endpoint for this test.

A 20-day chronic toxicity test using the juvenile polychaete, *Neanthes arenaceodentata*, was conducted by a subcontract laboratory according to Protocol for Juvenile Neanthes Sediment Bioassay (EVS, 1995) and *Recommended Guidelines for Conducting Bioassays on Puget Sound Sediments* (PSEP, 1995). The juvenile polychaetes were obtained from a laboratory culture supllied by the subcontract laboratory. The endpoints for this test were survival and growth (change in dry weight).

Specific quality assurance/quality control procedures for all three toxicity tests may be found in the *1998 NPDES Sediment Baseline Monitoring Plan for the West Point Outfall-Sampling and Analysis Plan* (King County, 1998).

SHELLFISH AND ALGAE

The uptake of contaminants by marine organisms occurs through ingestion of food and detrital particles, water exchange at feeding and respiratory surfaces, and adsorption of chemicals onto body surfaces. These contaminants may be stored in skeletal material, concretions, and soft tissues (Kennish, 1998). Biological monitoring is a component of the County's ambient and point source monitoring programs, as contaminants may be bioaccumulated by shellfish and algae.

Clam tissues are monitored for organic and metal contaminants and bacteria (fecal coliform and enterococcus). These measurements provide an indication of potential impacts to both shellfish and to humans that consume them. Chlorinated organics (chlorine atoms attached to organic compounds) have been used in pesticides since the 1940s and tend to accumulate in lipid tissue. Percent lipids in shellfish are also monitored as this parameter affects the concentration of organic pollutants accumulated.

Algae are monitored for metals as it is well documented that algae absorb metals directly from seawater (Phillips, 1994; Hou and Yan, 1998). Algae are used as a biomonitor to assess metal concentrations in intertidal areas as it is difficult to measure metal concentrations in seawater.

Shellfish and Algae Sampling Methods

Field Methods. The King County Environmental Services Section collected shellfish samples. Butter clams from each sampling station were collected by digging with shovels in the vicinity of siphon holes. A tarp was placed next to the digging site and excavated sediment was placed on the tarp to minimize disturbance to other organisms. The sediment was replaced after clams of sufficient size were removed. After the required amount of shellfish was obtained, the clams were placed in watertight plastic bags and stored on ice until delivered to the laboratory. Clams collected for metals and organics analyses were wrapped in aluminum foil prior to placement in plastic bags. A minimum of five butter clams (*Saxidomus giganteus*) were collected for each composite sample, with a minimum of 100 grams of tissue necessary for analysis.

Algae samples were collected by the King County Environmental Services section. Algae samples, composed entirely of *Ulva fenestrata*, were collected in glass jars and consisted of only attached healthy algae (i.e., discolored or free-floating algae were not collected). It is the sampling policy to collect only the most prevalent edible algae wherever possible, and there was sufficient *Ulva fenestrata* at all the sampling stations to adhere to this policy. After the required amount of algae were obtained, the jars were stored on ice until delivered to the laboratory.

Laboratory Methods. Shellfish samples were processed in accordance with PSEP recommended protocols (PSEP, 1996). Before the clams were opened, the shells were cleaned with a brush and tap water to remove sand and other material adhering to the shells. The shells were then given a final rinse with deionized water. Tissues from each clam were removed with stainless steel scalpels, composited with their liquor, and then homogenized with a stainless steel blender. Samples were frozen until analyzed with the exception of the sample portion removed for fecal coliform analysis. The fecal coliform and enterococcus analyses were initiated immediately following processing.

Algae samples were processed at the King County Environmental Laboratory. Algae were rinsed with deionized water to remove sand and other material adhering to the blades. Sample portions obtained for each station were processed in a stainless steel blender. Samples were then frozen until analyzed.

The King County Environmental Laboratory analyzed all shellfish and algae parameters. Methods and detection limits are provided in Table 2-6. All metals were analyzed using ICP emission spectroscopy with the exception of mercury. Mercury was analyzed by cold-vapor atomic absorption spectrophotometry. Semi-volatile organics were extracted with an organic solvent and then analyzed by GC/MS. Pesticides and PCBs were extracted with organic solvents and then analyzed using a GC equipped with an ECD. Bacteria samples were processed within eight hours of sample collection and analyzed by multiple-tube fermentation technique.

All samples were analyzed within their respective hold times and quality assurance/quality control procedures included the use of blanks, duplicates, and surrogates and spikes where appropriate. All data were reviewed by section supervisors prior to entry into the LIMS database.

Table 2-6. Laboratory Methods and Detection Limits for Shellfish and Algae

Parameter	Units	MDL	Method
Total Solids	%	0.005	SM2540-G
Total Lipids	%	0.1	KCEL OR 07-01-001
Metals, total, ICP-MS	mg/kg	variable[1]	KCEL 16-02-003
Mercury, total, CVAA	mg/kg	0.004	KCEL 16-01-003
Semivolatile Organics	µg/kg	variable[1]	SW 846 8270
Pesticides/PCBs	µg/kg	variable[1]	SW 846 8080
Fecal Coliform Bacteria	MPN/100g	20	KCEL MC 6.1.2
Enterococcus Bacteria	MPN/100g	20	KCEL MC 6.3.2

[1]Detection limits vary with parameter analyzed. Detection limits for individual samples and analytes are provided in Appendix C.

BENTHIC INFAUNA

Marine benthic communities are useful indicators of sediment quality as they spend the majority of their lives in direct contact with sediments. Benthic organisms can accumulate harmful metal and organic pollutants by ingesting contaminated sediment, eating contaminated prey, or by adsorbtion from the overlying or pore water. There is potential for contaminants to be passed up the food web to other organisms, since benthos are themselves food for fish and other animals.

Benthic communities can be investigated in many ways. Diversity indices, which are a reflection of the numbers and abundances of individuals within a community, are a common and useful method of assessing communities. Total abundance, or the total number of organisms, as well as total species abundance are other ways of describing communities.

Benthic community analysis was conducted in 1998 as part of King County's NPDES monitoring to determine if the wastewater discharge at West Point is having an impact on the surrounding benthos. Samples were collected from six sites around the outfall. Sediment chemistry analysis was conducted concurrent with benthic sampling. Communities were investigated by calculating diversity indices, calculating total and species abundances, looking at populations of pollution tolerant and sensitive species, and by determining proportion of individuals in major taxonomic groups. Spatial variation and correlation with physical conditions (sediment grain size, water currents) was also explored.

Field and Identification Methods

Samples were collected using the entire contents of a single 0.1 m^2 van Veen grab. Three replicates samples were collected at each site. After collection, samples were immediately sieved through a 1 millimeter screen and all material retained on the screen was preserved with 10% buffered formalin. Samples were later rinsed of formalin and stored in 70% alcohol. Preserved animals were sorted into the major taxonomic groups: Polychaeta, Crustacea, Mollusca, and miscellaneous (e.g., echinoderms, nemerteans, sipunculans). Samples were then sent out to taxonomic experts for further identification.

All animals were identified to the lowest possible taxonomic level, usually species. Identifications were performed by Jeff Cordell (Crustacea), Kathy Welch (Polychaeta), Allan Fukuyama (Mollusca), Valerie Hironaka and Allan Fukuyama (Echinodermata and misc.), and Phil Lambert (Holothuroidea). Quality assurance identifications were performed by Kevin Li (Crustacea), Eugene Ruff (Polychaeta), Susan Weeks (Mollusca), and Scott McEuen (Echinodermata and misc.).

Following identification, the data set was reviewed and some species were eliminated as they represented incidental catches (e.g., nematodes), were pelagic species (e.g., copepods), or were colonial organisms that could not be accurately quantified (e.g., bryozoans and ascidians). It should be noted that colonial organisms were included in the tabulated data as either present or absent but elimated from the calculation of diversity and abundance indices.

REGULATORY STANDARDS

Regulatory standards and guidelines for water quality have historically focused on those parameters that are of concern to human health. As a result, monitoring programs and criteria were concerned with bacteriological characteristics of surface waters. The focus of water quality guidelines has since expanded to include the health of aquatic organisms, resulting from the widespread use of pesticides, industrial and commercial uses of the Seattle waterfront, and the overall increase in concerns about water quality in Puget Sound. Washington State has implemented water quality standards for both surface waters and marine sediments.

The use of bacterial indicators and water quality criteria is necessary in order to evaluate data obtained from monitoring programs. Water quality management decisions are then based upon these findings. In addition to their use as assessment tools, environmental quality guidelines provide a basis for the development of site-specific water quality objectives for environmental contaminants. These guidelines may also be used to identify the need for source controls to reduce the input of contaminants into marine waters.

The EPA has established nationwide water quality criteria for specific pollutants, such as trace metals and PAHs. The priority is on those pollutants that show immediate toxic effects or have the potential to accumulate in the food chain. The Clean Water Act requires the State to adopt federal water quality criteria or promulgate their own standards which afford equal or better protection to sensitive organisms.

Washington State Standards for Water

Washington State currently has marine surface water quality standards for several contaminants, including metals, pesticides, and PCBs. These standards were derived for the protection of a variety of uses, including human health and the propagation and protection of fish, shellfish, and wildlife. Water quality standards for these compounds are not provided in this report, since the compounds were not analyzed as part of the ambient or point source monitoring programs. However, these standards may be obtained from the Washington State Department of Ecology and are available on their website at http://www.wa.gov/ecology/wq/standards.

Washington State Standards for Fecal Coliform Bacteria

Washington State divides surface water uses into five classes: AA, A, B, C, and Lake. Bacteria concentrations in samples taken from marine waters for both the ambient and point source monitoring programs are compared with the Class AA marine water standard and freshwater samples are compared to the Class AA freshwater standard (Table 2-7).

The state fecal coliform standards are expressed as geometric mean values. The reason for this is due to the high variability in fecal coliform counts, as bacteria tend to multiply exponentially. Transforming the data using natural logarithms can reduce this variability. This reduces the apparent differences between very high and very low numbers and also simplifies plotting the data by numerically compensating for the exponential growth rate of bacteria. Sample results obtained for King County's monitoring programs are expressed as a moving geometric mean to facilitate comparisons with state bacteria standards. This value is obtained by taking the geometric mean value for the 30 most recent samples as directed by the National Shellfish Sanitation Program guidelines for systematic random sampling.

As well as the moving geometric mean standard, no more than 10 percent of the samples used to obtain the moving geometric mean value may exceed a defined upper limit. For the Class AA marine water standard this value is 43 colonies/100 ml and 100 colonies/100 ml for the freshwater Class AA standard. Fecal coliform levels below the method detection limit (MDL) are reported as <MDL. In order to calculate geometric means, any value reported as <MDL was assumed to be one.

The moving geometric mean is calculated by taking the results of the 30 most recent samples and applying the formula shown below. When a new value is determined, it becomes part of the moving mean and the oldest value is dropped.

Computing Geometric Means.

Each geometric mean is calculated by taking the sum of the natural logarithms of the sample values, dividing that number by the number of samples, and then taking the inverse natural logarithm. The formula is given below,

$$\textit{geometric mean} = \textit{antilog}\ \frac{1}{n} \Sigma \log Y$$

*where **n** equals the number of fecal coliform observations and **Y** equals an individual observation (colonies/100 ml).*

Table 2-7. Fecal Coliform Bacteria Standards (colonies/100 ml)

Class	Moving Geometric Mean[a]	Peak[b]	Comments
AA: Freshwater Marine	50 14	100 43	Exceptional quality suitable for water supply (domestic, industrial, and agricultural), stock watering, fish and shellfish, recreation, and wildlife habitat.
A: Freshwater Marine	100 14	200 43	Can be used for the same purpose as Class AA, but differs in the allowed maximum temperature, minimum level of dissolved oxygen, and pH.
B: Freshwater Marine	200 100	400 200	Listed as "good"; it can be used for industrial and agricultural water supply and secondary contact recreation.
C: Both	200	400	Listed as "fair"; it can be used for industrial water supply, fish migration, secondary contact recreation, commerce, and navigation.
Lake	50	100	Meets or exceeds the requirements for all or substantially all uses listed for Class AA waters.

[a] Geometric mean of the 30 most recent samples.

[b] Not more than 10 percent of the 30 most recent samples may exceed this value.

Source: WAC 173-201a, November 25, 1992; NSSP, 1995.

Washington State Standards for Sediment

Chemicals may occur in sediments as part of the natural environment, however, it is more likely that sediments become contaminated by industrial andmunicipal discharges and non-point sources. Sediment quality guidelines provide a means of assessing sediment quality which leads to informed management decisions regarding the sediments and overlying waters.

Several studies conducted in Puget Sound have found some sediments that are contaminated with pollutants such as petroleum hydrocarbons, PAHs, PCBs, and metals. Several of these contaminated sites have been associated with adverse effects on the fish and shellfish that come into contact with these compounds.

In 1991, Ecology promulgated the Sediment Management Standards (SMS) guidelines which contain numeric criteria for specific organic and metal compounds (Table 2-8). The standards specify, based on the best available knowledge, the levels of sediment contaminants at which no adverse effects to marine organisms are expected. These standards are derived from the Puget Sound Apparent Effects Thresholds (AETs) for selected compounds, which are based on biological testing results (EPA, 1988). Concentrations of compounds that do not exceed the SMS values are not expected to have long-term adverse effects on marine biological resources.

The standards for ionizable organic compounds and metals are presented on a dry weight basis (the wet weight concentration divided by the decimal fraction of the total solids value) while the nonionizable organic compounds are organic carbon normalized.

The presence of contaminants in sediments does not necessarily indicate that the sediments are toxic to marine organisms. An important factor to the toxicity of contaminants is how much of a toxic compound is available for uptake directly into an organism or accumulated through the food chain. In general, organic compounds, which make up the largest class of chemicals of concern, tend to become associated with the organic matter contained in sediments. The nonpolar, nonionizable organic compounds (such as chlorinated hydrocarbons, aromatic hydrocarbons, and phthalates) have a tendency to adhere to organic matter in water and sediments whereas substances that form ions (such as salts, acids, bases, phenols, and metals) dissolve in water.

Organic matter in sediment is a food source for many benthic organisms (organisms that live on or near bottom sediments). Too little organic matter will not support these organisms and too much will reduce the number due to natural toxic effects associated with microbial activity. The organic carbon content of sediments has been shown to be related to the bioavailability and toxicity of some organic compounds to aquatic organisms (Di Toro et al., 1991).

The toxicity of organic compounds in sediments appears to be more closely correlated to the concentration of organic carbon in the sediments rather than the dry weight concentration. Thus, a more accurate measure of contaminant toxicity can be assessed if the data are “normalized” for the total organic carbon

Table 2-8. Washington State Sediment Management Standards

Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold	Contaminant	Sediment Quality Standard	Lowest Apparent Effects Threshold
Metals	mg/kg dry weight		**Nonionizable Organic Compounds**	mg/kg organic carbon	µg/kg dry weight
Arsenic	57		1,2-Dichlorobenzene	2.3	35
Cadmium	5.1		1,4-Dichlorobenzene	3.1	110
Chromium	260		1,2,4-Trichlorobenzene	0.81	31
Copper	390		Hexachlorobenzene	0.38	22
Lead	450		Dimethyl phthalate	53	71
Mercury	0.41		Diethyl phthalate	61	200
Silver	6.1		Di-n-butyl phthalate	220	1400
Zinc	410		Butyl benzyl phthalate	4.9	63
			Bis (2-ethylhexyl) phthalate	47	1300
			Di-n-octyl phthalate	58	6200
Nonionizable Organic Compounds	mg/kg organic carbon	µg/kg dry weight	Dibenzofuran	15	540
			Hexachlorobutadiene	3.9	11
			N-Nitrosodiphenylamine	11	28
Total LPAHs [a]	370	5200	Total PCBs	12	130
Naphthalene	99	2100			
Acenapthylene	66	1300			
Acenapthene	16	500	**Ionizable Organic Compounds**	mg/kg dry weight	
Flourene	23	540			
Phenanthrene	100	1500			
Anthracene	220	960	Phenol	0.42	
2-Methylnaphthalene	38	670	2-Methylphenol	0.063	
Total HPAHs [b]	960	12000	4-Methylphenol	0.67	
Fluoranthene	160	1700	2,4-Dimethylphenol	0.029	
Pyrene	1000	2600	Pentachlorophenol	0.36	
Benzo(*a*)anthracene	110	1300	Benzyl alcohol	0.057	
Chrysene	110	1400	Benzoic acid	0.65	
Total Benzofluoranthenes	230	3200			
Benzo(*a*) pyrene	99	1600			
Indeno(1,2,3-*c,d*)pyrene	34	600			
Dibenzo(*a,h*)anthracene	12	230			
Benzo(*g,h,i*)perylene	31	670			

[a] Represents the sum of the following low molecular weight PAHs: Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, and Anthracene.

[b] Represents the sum of the following high molecular weight PAHs: Fluoranthene, Pyrene, Chrysene, Benz(*a*)anthracene, Benzo(*a*)pyrene, total Benzofluoranthenes, Indeno(1,2,3-*c,d*)pyrene, Dibenzo(*a,h*)anthracene, and Benzo(*g,h,i*)perylene.

Source: Ecology, 1995

(TOC) content. For this reason, the State standards for nonionizable organics are based upon concentrations that have been TOC normalized (Michelson, 1992). Organic carbon normalization is achieved by dividing the dry weight concentration by the decimal fraction of TOC content. However, when TOC values are very low (e.g. <0.2 %) it is not appropriate to normalize contaminant values, as even background levels may exceed regulatory standards. When the TOC content is less that 0.2%, dry weight values are more appropriate to use than organic carbon normalized values.

Washington State Standards for Biota

In addition to contaminants found in water and sediment, several contaminants have the potential to accumulate in the tissues of aquatic biota, such as fish and shellfish. Bioaccumulation in biota may affect not only the species directly accumulating the contaminants, but humans and other species that consume the affected species. Numerical tissue-residue guidelines provide a basis for assessing the hazards that tissue-laden contaminants pose to human health and wildlife, and therefore, a basis for regulating contaminant inputs into the environment. Ecology does not currently have tissue-residue standards; however, heavy metal concentrations in shellfish samples were compared with EPA guidelines.